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14. ABSTRACT <p>HF-induced fine-scale electron density variations and/or enhanced airglow in the ionosphere were investigated. These irregularities appear to trap waves and cause them to "self-focus." Knowing what irregularities exist is important for improving communications and for pure discovery research on wave-particle interactions in the lower ionosphere at high latitudes. To develop accurate models of its behavior, lower ionospheric structure must be known. Under this grant, we conducted telescopic imaging of heater-induced airglow at HAARP to optically measure fine structure in the ionosphere and to study airglow sources. In the presence of aurora and a strong blanketing E layer, HAARP was modulated at intervals of several seconds. For several cycles, small bright airglow spots were observed whenever HAARP was on. These spots are elongated horizontally, indicating drift motion, and are the same order of brightness as the aurora (several kiloRayleigh). Such bright artificial airglow was never recorded previously. These results were published in the journal <i>Nature</i>. When HAARP was operating without sporadic E at 2.75 MHz (second gyroharmonic) and the beam was aimed along the magnetic field lines, a starburst pattern was observed consisting of field-aligned filaments with a coronal appearance. During this campaign, bright structure was frequently observed during gyroharmonic transmissions.</p>						
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**ONR Grant: N00014-03-1-0978**  
**FINAL REPORT**

**Telescopic Imaging of Heater-induced Airglow at HAARP**

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## **I. Introduction**

The focus of this study was to investigate the fine-scale electron density variations in the lower ionosphere. These electron density variations, or irregularities, scatter radio waves at a number of wavelengths and cause scintillation effects. At high frequencies, these irregularities appear to trap waves and cause them to "self-focus." It is important to know what sorts of irregularities exist, both from the practical viewpoint of improving communications and also for pure discovery research on wave-particle interactions in the lower ionosphere at high latitudes. Scientists must know the structure of the lower ionosphere in order to develop accurate models of its behavior. Under this ONR grant, we proposed to conduct telescopic imaging of heater-induced airglow at HAARP in order to optically measure fine structure in the ionosphere.

## **II. Completed Tasks**

This effort was a continuation of research begun by Dr. Elizabeth Gerken at Stanford University as a graduate student under a separate ONR grant. While at Stanford, she designed and deployed a 16" Dobsonian telescope and a bore-sighted wide field-of-view camera to study fine structure in airglow. Upon graduation, Dr. Gerken was employed by Cornell as a research associate and continued this project. During the period of 9/03-1/05, she participated in a successful winter optics campaign (see Section III), presented talks and co-authored journal articles (see Section IV), assisted in the HAARP Open House, and designed an upgrade for the telescopic imaging system. The upgrade designed was carried out in collaboration with Keo Scientific, Inc. The upgrade included telecentric lenses, automated 6-position filter wheels, and a robotic mount. The design was presented to a committee of HAARP scientists and was approved for funding.

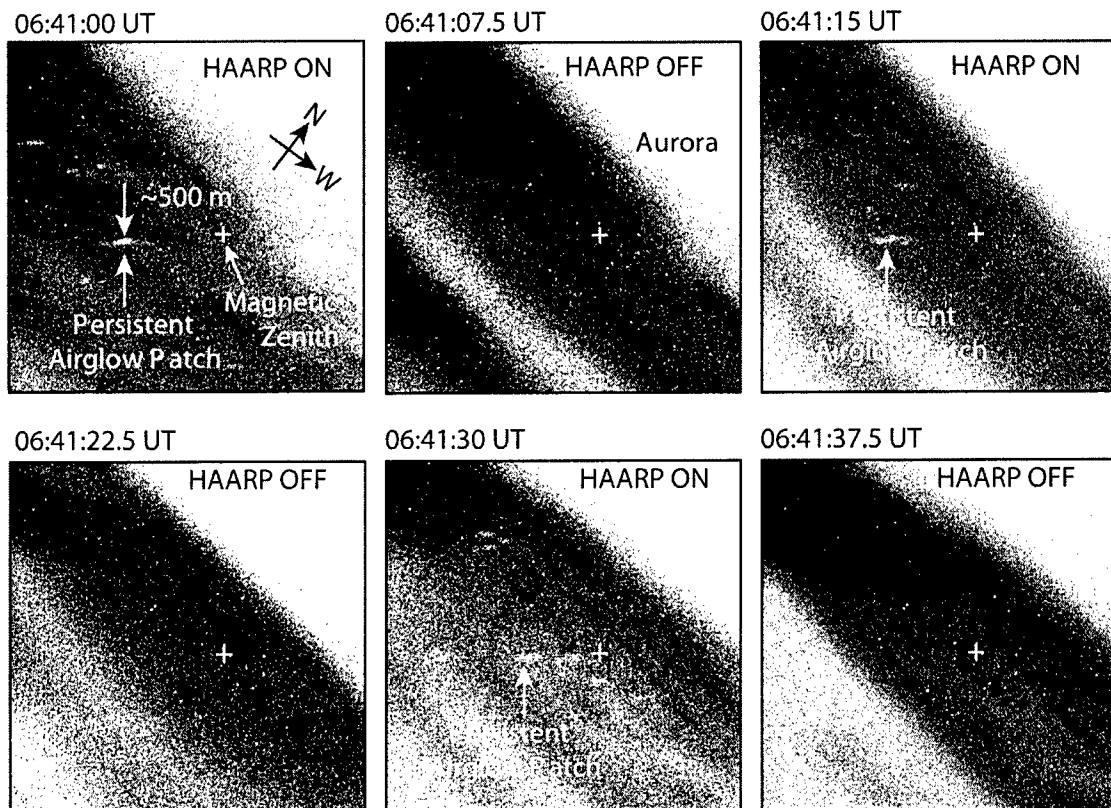
## **III. Significant Findings**

At middle latitudes in general, only the 630.0 nm oxygen line is bright enough to unambiguously be detected with rare cases of detectable 557.7 nm emissions [Bernhardt *et al.*, 1989b]. However, if a sporadic E layer develops, then the heating HF wave is able to interact with a much lower altitude, and bright 557.7 nm emissions (~55 R) are observed as patches [Djuth *et al.*, 1999; Kagan *et al.*, 2000]. At high latitudes, however, the nighttime E layer is typically created by auroral precipitation and is associated with strong ionospheric absorption and bright auroral emissions [Davies, 1965, p. 276]. In the February 2002 HAARP optical campaign, green line emissions were frequently observed simultaneously with red line emissions but these observations were made in the absence of a strong E layer, and the emissions appear to

have been generated in the F layer. In the March 2004 HAARP optical campaign, however, very bright ( $\sim 9$  kR) green line airglow emissions were observed in kilometer-scale patches between auroral arcs during blanketing E-layer conditions [Pedersen and Gerken, 2005].

## Structured E-layer airglow emissions

These images were observed on March 10, 2004 when HAARP was operating at 5.95 MHz and the beam was aimed along the magnetic field lines. This transmission occurred in the presence of aurora and when there was a strong blanketing E-layer. HAARP was turned on and off at an interval of several seconds. For several cycles of the transmission, small bright airglow spots were observed whenever HAARP was on. These spots are elongated horizontally indicating drift motion. The spots are on the same order of brightness as the aurora (several kiloRayleigh) and such bright artificial airglow has never been recorded before. Only the HAARP telescopic imaging system was equipped to record the structures.

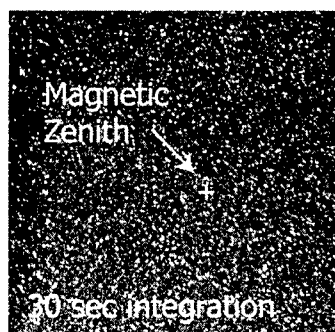


This unprecedented observation of airglow bright enough to be visible to the naked eye was detected only by the HAARP telescopic imaging system [Pedersen and Gerken, 2005]. This

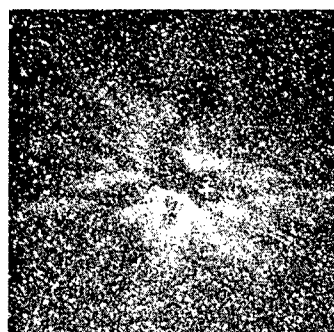
novel instrument has proven to be a valuable addition to the HAARP imaging suite, which is also comprised of all-sky and intermediate field-of-view imagers. During both this transmission and even more recent ones at electron cyclotron harmonics [Djuth *et al.*, 2005; Kosch *et al.*, 2005], recordings by the HAARP telescopic imager revealed the presence of ionospheric structure on a scale too small to be observed when using imagers with larger fields of view.

### Structured F-layer airglow emissions

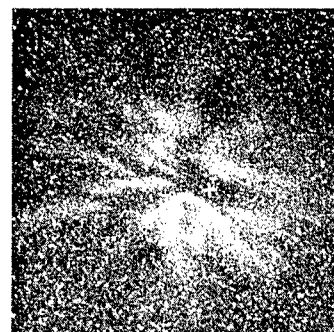
These images were observed on March 20, 2004 when HAARP was operating at 2.75 MHz and the beam was aimed along the magnetic field lines. The starburst pattern indicates that the observed structure consisted of field-aligned filaments accounting for the coronal appearance. These structures were generated when the HAARP transmitter was operated at the local second gyroharmonic frequency for the altitude of the interaction region. During this campaign bright structure was frequently observed during gyroharmonic transmissions.



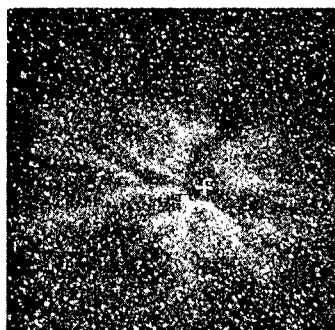
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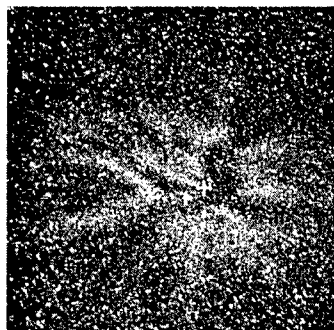
06:17:30 UT  
HAARP ON



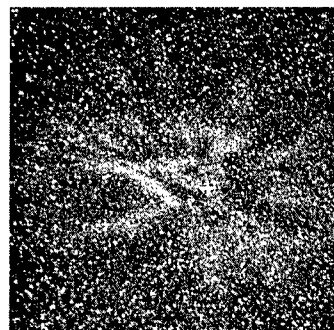
06:18:00 UT  
HAARP ON



06:18:30 UT  
HAARP ON



06:19:00 UT  
HAARP ON



06:19:30 UT  
HAARP ON

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